WATERTOWN ARSENAL LABORATORY

EXPERIMENTAL REPORT

NO. WAL. 640/91

ARMOR AND WELDING

Metallurgical Examination of Armor and Weld Joint Samples from Russian Medium Tank T-34 and Heavy Tank KV-1

BY

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and

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DATE 24 November 1943

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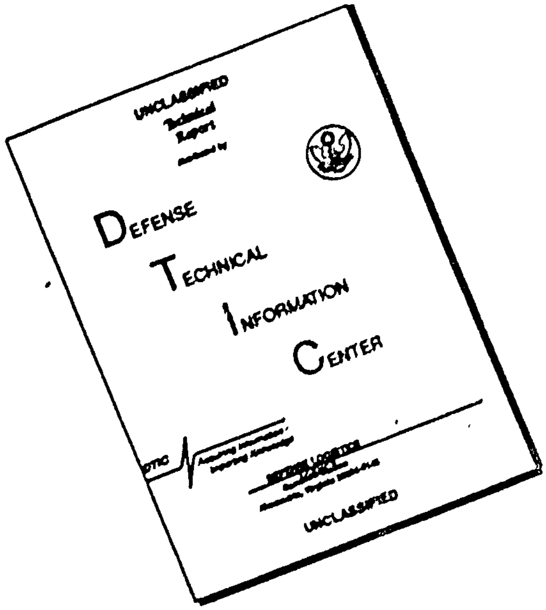

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Subject: Watertown Arsenal Laboratory Report No. WAL 640/91.

To: Chief of Ordnance, U.S.A.
Pentagon Building
Washington 25, D. C.

Attn: SPOTB - Intelligence Unit

1. In accordance with Ordnance Department Order No. 327, Change No. 3, there are inclosed herewith twenty (20) copies of Watertown Arsenal Laboratory Report No. WAL 640/91, entitled "Armor and Welding - Metallurgical Examination of Armor and Weld Joint Samples from Russian Medium Tank T-34 and Heavy Tank KV-1." This report is in completion of the test program outlined in basic letter - O.O. 400.112/4376(s), Wtn. 451.25/157(s), dated 27 August 1943.

2. An additional copy of this report has been forwarded to SPOTB, Special Steels and Welding, as the agency directing the examination. It is suggested that one copy of the inclosed report be forwarded to the following: Tank-Automotive Center, Attn: Engineering Section, Armor & Welding Group; Ordnance Research Center, Aberdeen Proving Ground, Attn: Armor Development Branch; SPOTT; and, SPOTC. It is assumed that one of the inclosed copies will be filed in the Ordnance Technical Library, for which purpose index cards are attached.

3. Four basic alloy steel types: Mn-Si-Ni-Cr-Mo, Mn-Si-Mo, Mn-Cr-Mo, and Cr-Mo, exhibiting a wide variation in steel quality, were used. Components of the Medium Tank T-34 were heat treated to very high hardness levels (429 - 495 Brinell) while the components of the Heavy Tank KV-1 were heat treated to hardnesses more nearly approaching American practice (285 - 321 Brinell). Joint design is characterized by dovetailing. Fit-up is fairly rough. Two types of ferritic electrodes, one of plain carbon-manganese and the other of similar analysis with a substantial molybdenum addition evidently were used. Austenitic electrodes were used, apparently indiscriminately, in making two of the weld deposits. Shallow penetration, poor fusion, and severe undercutting were observed in most of the welds and are probably due to improper manipulation of electrodes which may not have entirely suitable operating characteristics.

For the Commanding Officer:

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Watertown Arsenal Laboratory
Report Number WAL 640/[illegible]
Problem Number D-2.1 24 November 1943

ARMOR AND WELDING

Metallurgical Examination of Armor and Weld Joint Samples from Russian Medium Tank T-34 and Heavy Tank KV-1

OBJECT

To make complete metallurgical examination of subject armor and weld joints.

SUMMARY OF RESULTS

ARMOR

1. The four types of alloy steels used are as follows:

   a. Mn-Si-Mo alloy steel for rolled plates 5/8 inch to 3/4 inch in thickness.

   b. Cr-Mo alloy steel for 1-1/4 inch thick rolled armor.

   c. Ni-Cr-Mo alloy steel for 3-5/8 inch thick cast armor.

   d. Mn-Si-Ni-Cr-Mo alloy steel for both cast and rolled components 5 inches and 1-7/8 inches in thickness respectively.

The silicon content of the Mn-Si-Ni-Cr-Mo and Mn-Si-Mo steels is high, ranging from 1.0 - 1.5% Si. All the compositions provide hardenability adequate for satisfactory quench hardening of the sections.

2. With the exception of one component, namely, the bow casting from the Medium Tank T-34 which is primarily a structural element, the armor components were heat treated by quenching, probably in oil, followed by tempering. High temperature transformation products resulting from incomplete quench hardening were detected in some of the heat-treated armor sections.

3. The armor components of the Medium Tank T-34 were heat treated to very high hardness levels (429 - 495 Brinell) probably in an attempt to obtain maximum resistance to penetration even at the expense of structural stability under ballistic attack. The components of the Heavy Tank KV-1 were heat treated to hardnesses more nearly approaching American practice (285 - 321 Brinell).

4. The steel quality of the rolled armor sections varies from poor to excellent. Wide variations in production technique are indicated. Some rolled armor components were cross-rolled while others appear to have been straight-away rolled. The turret casting from the Medium Tank T-34 is of

good quality, while that of the Heavy Tank KV-1 contains excessive amounts of hot tears in the section examined. The bow casting is extremely unsound, containing excessive shrinkage.

WELDING AND JOINT DESIGN

5. The joint design is characterized by dovetailing such that the edge of the lighter plate is set into a niche machined or flame-cut in the heavier plate sufficient to bring the lighter plate surface approximately flush with the surface of the edge of the heavier plate. Fit-up is fairly rough. All welding appears to have been done in the flat or horizontal fillet position.

6. Two types of ferritic electrodes, one of a carbon-manganese and the other of a similar analysis with a substantial molybdenum addition, evidently were used for most of the welding. Base metal cracking of the under-bead type was negligible, and since all weld deposits appear to have been made on armor in the final heat-treated condition without the use of preheat it is probable that a ferritic electrode with a suitable all-mineral type coating was used. Austenitic electrodes were used, apparently indiscriminately, in making two of the weld deposits.

7. Shallow penetration, poor fusion, and severe undercutting were observed in most of the welds and are probably due to improper manipulation of electrodes which may not have entirely suitable operating characteristics. These obvious defects, together with low strength and poor metallurgical structure of ferritic weld deposits, indicate that the welded joints would have poor resistance to severe shock.

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INTRODUCTION

Three welded joint sections from a Russian Medium Tank T-34 and one welded joint section from a Russian Heavy Tank KV-1 were forwarded to this arsenal by Aberdeen Proving Ground for metallurgical examination of rolled and cast armor and welded joints in accordance with instructions of the Office, Chief of Ordnance[1].

MATERIALS AND TEST PROCEDURE

Locations of samples, as taken from the complete vehicles are indicated on Sketches A, B, and C furnished with the basic correspondence (see Appendix A). Macroetched cross sections cut perpendicular to each weld joint show the four samples to be made up of the following components:

Sample No. 1 (Figure 1) Medium Tank. Sloping top and lower rolled homogeneous armor hull front plates attached to bow casting by two dovetailed joints held by four shallow penetration weld deposits.

Sample No. 2 (Figure 2) Medium Tank. Rolled homogeneous hull roof plate attached to rolled homogeneous top sloping front plate by incomplete penetration angle joint welded from both sides of plate.

Sample No. 3 (Figure 2) Medium Tank. Rolled homogeneous turret top plate attached to turret sidewall casting by incomplete penetration, partially dovetailed, angle weld joint welded from both sides of plate.

Sample No. 4 (Figure 2) Heavy Tank. Rolled homogeneous turret top plate attached to sidewall casting by incomplete penetration, partially dovetailed, corner joint welded from outside of joint only.

Samples for chemical analyses, tensile tests, hardness surveys, macroetching and microscopic examination were cut from each armor section. Samples for chemical analyses, hardness surveys, macroetching and microscopic examination of each weld joint were taken. Results of these tests are discussed in the following sections.

DATA AND DISCUSSION

ARMOR

1. Chemical Analyses

The analyses of the nine armor specimens contained in the four submitted welded sections are included in Table I. Four basic type analyses are recognizable, consisting of the following alloys:

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[1] See Appendix A - Basic Correspondence

a. Mn-Si-Ni-Cr-Mo

The components of this type analysis consist of two 1-7/8 inch thick rolled homogeneous plates, and a 2-3/8 inch thick cast turret side-wall section from the Medium Tank T-34, all of which fall within the following range of chemical composition:

C	Mn	Si	Ni	Cr	Mo
.23/.28	1.20/1.27	1.09/1.45	1.24/1.32	.85/1.05	.195/.22

Also included in this type analysis is a bow casting from the Medium Tank T-34 which has a maximum thickness of approximately 5 inches. The bow casting has higher manganese and silicon contents than the other armor sections in the same category, namely, 1.5% Mn and 2.3% Si.

b. Mn-Si-Mo

The two components of this type analysis consist of 5/8 inch and 3/4 inch thick rolled homogeneous plates from the Medium Tank T-34 lying within the following range of chemistry:

C	Mn	Si	Mo
.25/.36	1.27/1.33	1.14/1.59	.20

Residual amounts of nickel and chromium are also present. This alloy is exactly similar in manganese, silicon, and molybdenum contents to the previously considered Mn-Si-Ni-Cr-Mo steel.

c. Ni-Cr-Mo

The one component of this type analysis consists of a 3-5/8 inch thick turret sidewall casting for the Heavy Tank KV-1. The composition is the following:

C	Mn	Si	Ni	Cr	Mo
.30	.44	.34	2.91	1.47	.27

d. Cr-Mo

One 1-1/4 inch thick rolled homogeneous plate, from the Heavy Tank KV-1, of the following analysis is of the Cr-Mo type:

C	Mn	Si	Cr	Mo
.32	.41	.32	2.34	.25

2. Hardenability

Jominy bars, machined from two of the Mn-Si-Ni-Cr-Mo steel components of the Medium Tank T-34, and from the Ni-Cr-Mo and Cr-Mo steel components of the Heavy Tank KV-1 were austenitized for 3 hours at 1675° F.

and end quenched according to the standard procedure. The hardenability curves are presented in Figures 3 and 4, and pertinent data summarized in Table II.

All of the four steels possess hardenability adequate to permit satisfactory quench hardening through the thickness of the section upon oil quenching.

3. Hardness Surveys

Rockwell C and Brinell hardness surveys were made on surfaces through the thickness of the plates. The results of the hardness surveys are contained in Figure 5, and are summarized as follows:

HARDNESS SURVEYS OF RUSSIAN ARMOR

Sample	Armor Section	Thickness inches	Hardness Range Through Cross Section Brinell	Rockwell C
1	Bow Casting	5	200 - 248	--
	Lower Sloping Front Plate	1-7/8	444	44 - 47
2	Top Sloping Front Plate	1-7/8	444 - 461	43.5 - 47.5
	Hull Roof Plate	3/4	429	44 - 45.5
3	Turret Top Plate	5/8	495	50.5 - 51.5
	Cast Turret Sidewall	2-3/8	444 - 495	45 - 50.5
4	Turret Top Plate	1-1/4	321	30 - 34.5
	Cast Turret Sidewall	3-5/8	285 - 293	25 - 30

4. Physical Properties

The tensile properties of all armor components with the exception of the bow casting of Sample 1 were determined, and are listed in Table III. Excessive porosity in the bow casting prevented adequate determination of its physical properties. The elongation and reduction of area of the rolled and cast armor sections compare favorably with the same properties of domestic good quality steel at comparably high tensile strengths.

5. Macrostructure and Microstructure

Medium Tank T-34

Sample 1

Lower Sloping Front Plate. The hot acid etched structure of the 1-7/8 inch thick rolled homogeneous lower sloping front plate indicates moderately clean, cross-rolled steel with some residual ingotism evident as shown by the differential etching characteristics of the middle third of the cross-section (Figure 6A). Typical silicate-type inclusions are shown in Figure 6B.

The microstructure consists of relatively coarse acicular martensite having an A.S.T.M. grain size of #3 - 4. The steel was completely quench hardened, probably in oil, and possibly tempered at some temperature not over 500° F., since no evidence of martensite decomposition can be found (see Figures 6C and 6D).

Bow Casting. The bow casting is extremely porous with shrinkage cavities as large as 1/2 inch in diameter occurring in the midsection of the casting. The hot acid macroetch reveals a very coarse-grained structure and a large amount of fine porosity (Figure 7A). At low magnification, the microstructure exhibits a coarse Widmanstätten pattern with ferrite envelopes at the austenite grain boundaries (Figure 7B). Oriented spheroidized carbides are revealed at high magnification (Figure 7C), and some spheroidized carbides occur in the ferrite envelopes (Figure 7D).

The microstructure of the bow casting indicates that the heat treatment employed consisted of either a normalizing and tempering treatment, or a tempering treatment alone. The lack of a hardening treatment is very unusual for an armor component. The bow casting, as incorporated into the T-34 tank is, however, primarily employed as a structural member. Only a very narrow portion of the casting is exposed to ballistic attack; and because of the angles at which the top and lower sloping front plates are attached, the exposed portion of the bow casting resembles the point of an arrowhead.

Sample 2

Top Sloping Front Plate. The hot acid macroetched structure of the 1-7/8 inch thick rolled homogeneous top sloping front plate is considerably different from that of the lower sloping front plate (compare Figure 8A to Figure 6A). The top sloping front plate was probably straight-away rolled, that is, the reduction to the final gage was performed by rolling in a constant direction (see Figure 8A). The steel quality is poor, many elongated stringers of nonmetallic inclusions being found throughout the cross-section. Two general types of stringers occur, one consisting of small, friable, alumina-type inclusions and the other of disconnected silicate-type inclusions (Figures 8B and 8C).

The microstructure consists of martensite grains having an A.S.T.M. grain size of #6, with some rejected pearlite and ferrite at the martensite grain boundaries (Figures 8D and 8E). The presence of the high temperature transformation products indicates insufficient quench hardening since the steel possesses adequate hardenability for its section size. The microstructure reveals that the armor was not tempered at a temperature in excess of 400° - 500° F.

Hull Roof Plate. The 3/4 inch thick rolled homogeneous hull roof plate of the Medium Tank T-34 was produced by a straight-away rolling process (Figure 9A). As compared with current domestic standards, the steel is of inferior quality, with numerous elongated silicate-type inclusions distributed throughout the cross-section (Figure 9B). The microstructure consists of grains of martensite with pearlite and ferrite rejected at the grain boundaries, as well as occasional grains of coarse pearlite (Figures 9C, 9D, and 9E). The presence of high temperature transformation products in this thin plate made of steel having high hardenability, indicates improper hardening technique. The hull roof plate was possibly tempered at a low temperature, not in excess of 500° F.

Sample 3

Turret Top Plate. The 5/8 inch turret top plate was also produced by a straight-away rolling process (Figure 10A). The steel is sound and relatively free from nonmetallics. The microstructure consists of martensite grains having an A.S.T.M. grain size of #4 (Figures 10B and 10C). The uniform martensitic microstructure indicates good hardening practice and a low tempering temperature.

Turret Sidewall Casting. The hot acid macroetched structure of the 2-3/8 inch thick turret sidewall casting from the Medium Tank T-34 reveals a very fine dendritic structure and fine shrinkage confined to the middle third of the section thickness (Figure 11A). The steel is moderately clean, containing randomly distributed globular nonmetallics (Figure 11B). The microstructure is essentially martensitic with an A.S.T.M. grain size of #5 (Figure 11C). Pearlite and ferrite occur at the martensite grain boundaries in the dendritic axes (Figure 11D), while the higher alloy dendritic fillings are completely martensitic (Figure 11E). The casting was possibly tempered at a low temperature.

Heavy Tank KV-1

Sample 4

Top Plate. The hot acid macroetched structure of the 1-1/4 inch rolled homogeneous turret top plate indicates the steel to have been cross rolled (Figure 12A). Scattered stringers of nonmetallics occur in both longitudinal and transverse sections. The steel is moderately unclean, with silicate-type inclusions found throughout the cross-section (Figure 12B). A moderate degree of banding is evidenced at low magnifications, with the steel having a grain size of A.S.T.M. #6 (Figure 12C).

The microstructure consists of tempered martensite, ferrite, and spheroidized carbides. The presence of high temperature transformation products indicates improper hardening technique since the hardenability of the steel is extremely high (Figure 4). A tempering temperature of 1050° - 1150° F. was probably employed.

Turret Sidewall Casting. The hot acid macroetched structure of the 3-5/8 inch thick turret sidewall casting from the Heavy Tank KV-1 reveals many hot tears extending down for a considerable distance into the metal (Figure 13A). The dendritic structure is most pronounced in the middle third of the cross-section. The steel is very clean, with only scattered nonmetallics visible at a magnification of X100 (Figure 13B).

The microstructure consists of tempered martensite with very small amounts of ferrite and grain boundary carbides occurring irregularly in the dendritic axes (Figures 13D and 13E). The hardness and microstructure indicate a tempering temperature of approximately 1200° F.

6. General Considerations (Armor)

The analyses of the armor components from the Medium Tank T-34 demonstrate judicious selection of alloying elements from the viewpoint of conservation. The Mn-Si-Mo analysis for the light gage armor is an excellent example of a steel containing very small amounts of any strategic alloy. The Mn-Si-Ni-Cr-Mo analysis was probably developed to provide increased hardenability for application to armor of heavier gage. The silicon content of these steels is much greater than that of domestic cast and rolled armor. It has been found difficult in American practice to produce high silicon armor steels low in nonmetallic content.

The Ni-Cr-Mo 3-5/8 inch thick turret sidewall casting and the 1-1/4 inch thick Cr-Mo rolled steel plate from the Heavy Tank KV-1 are both somewhat similar in composition to currently produced domestic heavy armor. The Cr-Mo steel has a considerable excess of hardenability when applied to 1-1/4 inch thick plates.

The subject armor is considerably harder than American armor of comparable thicknesses. The comparison between the average hardness of currently produced American armor and the subject Russian armor is as follows:

Plate Thickness	Type Armor	Hardness Range of American Armor BHN	Hardness Range of Russian Armor BHN
5/8"	Machinable Rolled Homogeneous	320 - 350	---
5/8"	Hard Rolled Homogeneous	360 - 390	495
3/4"	Rolled Homogeneous	310 - 350	429
1-1/4"	Rolled Homogeneous	280 - 320	321
1-7/8" - 2"	Rolled Homogeneous	260 - 290	444 - 461
2" - 2-3/8"	Cast Homogeneous	235 - 270	444 - 495
3-5/8" - 4"	Cast Homogeneous	200 - 230	285 - 293

It is the practice in this country to reduce the hardness of armor with an increase in thickness to maintain good resistance to the shock resulting from the impact of large caliber projectiles. It has been demonstrated by ballistic tests that there is an optimum hardness for each thickness of armor for maximum ballistic properties, and that the optimum hardness is an inverse function of thickness under overmatching projectile conditions at normal incidence of fire. The maximum ballistic properties include not only resistance to penetration, but also resistance to spalling, shattering, or cracking under the impact of both overmatching armor-piercing and deforming projectiles, the latter type producing a high order of shock impact.

American armor does not generally fail structurally upon complete penetration; the projectile either pushes the material aside, or punches out a plug, leaving the armor still capable of affording protection against further ballistic attack. On the other hand, very hard armor has a tendency to fail structurally when impacted by projectiles of sufficient caliber and velocity to produce complete penetration; the armor breaking up or cracking so extensively as to effectively decrease its ability to resist further impacts. Hard armor would be expected to have higher ballistic limits against undermatching projectiles than soft armor at all obliquities, and would possibly have superior resistance to penetration of overmatching projectiles at very high obliquity. In the case of hard armor under ballistic attack at high obliquities, it is believed that the high hardness would be instrumental in deflecting the projectile in such manner as to increase its obliquity, thereby enabling the armor to defeat the projectile.

In designing armor to afford maximum protection against armor-piercing high explosive projectiles intended to detonate after complete penetration of the armor, the consideration of resistance to penetration may, in some cases, be more important than resistance to shock. The subject Russian armor appears to have been designed for maximum resistance to penetration of undermatching projectiles at all obliquities and possibly matching and overmatching A.P. H.E. projectiles at high obliquities. Armor up to 3 inches in thickness and having hardnesses in the range of 400 - 500 Brinell would be expected to evidence extremely brittle behavior under normal and low obliquity impact of overmatching armor-piercing projectiles.

The quality of the rolled steel armor components covers the entire range from poor to excellent, indicating wide variations in production technique. Several of the plates were incompletely quench hardened although possessing hardenability adequate to quench harden through the section thickness.

WELDING AND JOINT DESIGN

1. Visual Examination

The surface appearance of the welds after removal of a heavy coat of paint was generally quite rough indicating inexperience on the part of the welders in using too high a current or improperly manipulating electrodes. Deposits A and C, Sample 1 (Figure 1), deposit B, Sample 2, and deposit A, Sample 3 (Figure 2) appear to have been welded in the flat position. None of these are completely filled with weld metal because of inadequate weaving of the electrode during deposition of the crown beads. All of the remaining deposits appear to have been welded in the horizontal fillet position and all show severe undercutting due to too high a current or improper manipulation of the electrode, which may not be entirely suitable in operating characteristics for welding in this position. If electrode had been held at slight angle and whipped (oscillated backward and forward to permit even solidification of metal) the amount of undercutting would have been less.

2. Chemical Analyses

Results of chemical analyses of samples machined from weld deposits are given in Table IV.

Two types of ferritic electrodes evidently were used. Ferritic deposits of joint samples, Nos. 1, 2, and 4, appear to have been made with a low alloy or plain carbon electrode, possibly with a small manganese addition. The remaining alloy content of these weld deposits appears to be due to pickup from the base metals. The lower manganese in weld deposit of Sample 4 corresponds with a lower manganese content of the base metals of this joint.

An austenitic electrode was used for the body of weld deposit A, Sample 2, and for the crown and body of weld deposit A, Sample 4 (Figures 2 and 15). The ferritic crown of the former deposit may have been made with the same type of electrode as was used for the inner deposit of this joint, the higher nickel and chromium being due to pickup from the underlying austenitic weld metal.

The weld metal analyses of the two deposits of joint Sample 3 indicate that a substantial molybdenum addition was introduced either in the core wire or coating of the electrode used in welding this joint.

3. Hardness Surveys

Results of Vickers-Brinell hardness surveys of weld deposits and weld heat-affected zones of base metals are summarized in Table V.

In general, both austenitic and ferritic weld metal hardnesses are low (185 to 250 standard Brinell*) with areas of higher hardness (250 - 324 Brinell) for some of the weld metal passes which are in contact with the base metals and have picked up higher carbon and alloy contents.

The ferritic crown deposit A, joint Sample 2, which has picked up a high nickel and chromium content from the underlying austenitic weld metal is of higher hardness (370 - 396 Brinell) than any of the other weld metal. The low carbon content of this deposit and the fact that it does not cover the whole of the crown, make it appear unlikely that this was an expedient intended to give a hard surface to the weld joint.

Maximum hardnesses of the base metals, a function of severity of weld-quenching cycle and carbon and alloy contents of the plate, range from 466 - 307 standard Brinell. A band near the outside of the weld heat-affected zone has been tempered by the welding heat to a much lower hardness.

4. Macroexamination

Macroetched sections through the weld deposits of joint Sample 1 (Figure 1) are shown in Figure 14, and macroetched sections of weld deposits of joint Samples 2, 3, and 4, are shown in Figure 15.

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* See note, Table V

The four weld deposits of Sample 1 appear to have been made with three to six passes of a ferritic electrode. Penetration and fusion are poor and there are several large gas holes in the weld metal. The rolled plates were welded as flame cut, but the dovetailing recesses in the bow casting show marks of a rough machining tool and evidently were prepared in a shaper. Mild steel strips have been inserted at the end of the lower front plate and have fused at one end into the outer weld deposit.

The inner deposit of Sample 2 was made with four passes of a ferritic electrode. The root of the outer deposit was made with a ferritic bead, the body with several passes of an austenitic electrode, and a portion of the crown with a ferritic electrode. Penetration and fusion at the root of the joint are poor. No particular purpose can be seen in the use of austenitic weld metal in this deposit.

The two weld deposits of Sample 3 appear to have been made with two passes each of a slightly different type of ferritic electrode from that used for the other three joints (see discussion of chemical analyses). The deposits have many large gas holes. Penetration at the root of joint is poor. Surfaces of the dovetailing recess in the turret sidewall casting show grinding marks.

Joint Sample 4 appears to have been made with a root deposit of three passes with a ferritic electrode followed by a body and crown deposit of five or six passes with an austenitic electrode. Fusion of the ferritic root is very poor and there is serious undercutting at the plate junction with the austenitic crown. The dovetailing recess in the turret sidewall casting was made by flame gouging as evidenced by surface appearance and presence of a heat-affected zone at this surface of macroetched section. Fitup of this joint is very poor.

Shallow but distinct heat-affected zone areas indicate that all welding was done without the use of preheat on armor in the final heat-treated condition.

5. Microexamination

Photomicrographs of structures in the weld deposits and fusion zone areas of the four samples are shown in Figure 16. Microstructure of the plain C-Mn ferritic electrode used in weld Samples 1, 3, and 4, is typically low carbon pearlite with excess ferrite in a dendritic pattern (upper left photomicrograph, Figure 16). Weld metal beads in contact with base metal have a higher proportion of carbides because of pickup of carbon from the armor. The small crack growing out of an area of incomplete penetration and the linear segregation of small inclusions in the weld metal are examples of defects found in these deposits (upper right and upper center left photomicrographs). Base metal structure adjacent to the fusion zones is the usual coarse-grained martensite.

Microstructure of ferritic root bead in outer deposit, Sample 2, (upper center left photomicrograph) consists of high transformation temperature carbides and excess ferrite with original dendritic pattern broken up by reheating by austenitic weld deposits. Ferritic beads at crown of outer weld deposit, because of higher alloy content picked up from underlying austenitic deposit, consists largely of low transformation temperature carbides in a ferritic background. This structure accounts for the higher hardness noted for this weld metal. A small weld metal crack was observed at fusion line of austenitic and ferritic crown bead weld metals (lower left center photomicrograph).

The microstructure of the root beads of the two weld deposits of Sample 3 (right lower center photomicrograph) consists of high transformation temperature carbides and excess ferrite. The original dendritic segregation has been largely broken up and carbides have been partially spheroidized by heat of subsequent welding passes. A much higher proportion of carbides is present, because of carbon pickup from plate, than in crown beads of same deposits. The microstructure of the latter (lower left photomicrograph) is low carbon pearlite with typical dendritic segregation of free ferrite.

A photomicrograph of junction of ferritic and austenitic weld metals of joint Sample 4 shows the former to consist of high transformation temperature carbides and ferrite with excess ferrite network at boundaries of grain system produced by heat of subsequent austenitic weld deposit. Two small fusion zone cracks extended from notches due to incomplete fusion of ferritic root bead and armor. A base metal crack in turret roof plate under ferritic weld deposit was associated with nonmetallic stringers in this rolled plate.

6. General Considerations (Welding and Joint Design)

The joint design is characterized by dovetailing which serves to locate the welds in positions protected from direct ballistic attack, eliminates any danger of bullet splash, and in most cases, reduces the amount of welding necessary to form the joint. The fitup is fairly rough. Little beveling was done. Complete penetration was not achieved in any of the joints. Fusion at the root of welds was very poor and several fusion zone cracks were observed to originate at notches due to lack of fusion.

All welding appears to have been done either in the flat or horizontal fillet position. Joints made in the latter position show severe undercutting probably due to improper manipulation of electrode.

Two types of ferritic electrodes evidently were used; one C-Mn, and the other of similar analysis with a molybdenum addition. The latter gave a very porous weld deposit. Base metal cracking of the underbead type was negligible and since all weld deposits appear to have been made on armor in the final heat-treated condition without the use of preheat, it is probable that a ferritic electrode with a suitable all-mineral type coating was used. Austenitic electrodes were used, apparently indiscriminately, in two joints.

The resistance of the four weld joints to severe shock would not be expected to be good because of shallow penetration, poor fusion, undercutting, and low strength of ferritic weld metal. These obvious defects are offset by a design which may minimize exposure of weld joints to ballistic attack.

TABLE I

Chemical Analyses of Russian Armor

Armor Section	C	Mn	Si	S	P	Ni	Cr	Mo	Cu	Al
Sample 1 (Medium Tank T-34)										
Top sloping front plate	.23	1.20	1.10	.026	.021	1.26	1.05	.215	.09	.025
Bow casting	.29	1.55	2.29	.021	.029	1.52	1.05	.25	.12	.015
Lower sloping front plate	.28	1.27	1.45	.018	.023	1.32	1.03	.22	.09	.02
Sample 2 (Medium Tank T-34)										
Top sloping front plate	.26	1.20	1.09	.028	.024	1.24	.90	.21	.09	.015
Hull roof plate	.25	1.27	1.14	.042	.018	.14	.10	.195	.11	.02
Sample 3 (Medium Tank T-34)										
Top plate	.36	1.33	1.59	.022	.017	.14	.05	.20	.12	.025
Cast turret sidewall	.26	1.20	1.37	.010	.018	1.26	.85	.195	.04	.015
Sample 4 (Heavy Tank KV-1)										
Top plate	.32	.41	.32	.016	.018	.16	2.34	.25	.11	.015
Cast turret sidewall	.30	.44	.34	.041	.016	2.91	1.47	.27	.10	.02

TABLE II

End-Quench Hardenability Data

	Bow Casting from Medium Tank T-34	Top Sloping Front Plate from Sample 1 (Med. Tank T-34)	Top Plate from Heavy Tank KV-1	Turret Side-wall from Heavy Tank KV1
Actual Thickness of Section - Inches	5	1-7/8	1-1/4	3-5/8
Hardness 1/16" from Quenched End. Rc	51.5	46.5	52	50.5
No. of 1/16th of an inch for a Drop				
of 5 Rc	Minimum hardness is 48.5 Rc	20	20	Minimum hardness is 46.5 Rc
of 10 Rc		Minimum hardness is 37 Rc	39	
to 43 Rc		16	32	
Hardness at 2-1/2" from Quenched End. Rc	48.5	37	41	46.5
Thickness of Plate Quenchable to 43 Rc in the Center - Inches (oil quench)	Greater than 5"	1.9	3.5	Greater than 4"

TABLE III

Physical Properties of Russian Armor

Direction of Tensile Specimen		Yield Strength 0.1% Offset psi.	Tensile Strength psi.	Elongation %	Red. of Area %	Brinell Hardness
SAMPLE 1 (Medium Tank T-34)						
Top Sloping Front Plate (1-7/8" Rolled Homogeneous)						
Longitudinal	1	172,000	219,000	10.0	44.9	430
"	2	171,000	217,000	12.1	49.0	
"	3	171,000	221,000	10.7	45.3	
"	4	167,000	214,000	12.1	49.4	
Longitudinal Average		170,250	217,750	11.2	47.2	
Transverse	1	149,000	202,000	10.0	37.6	
"	2	160,000	215,500	8.6	33.1	
"	3	167,000	217,500	7.9	34.0	
Transverse Average		158,700	211,700	8.8	34.9	
Lower Sloping Front Plate (1-7/8" Rolled Homogeneous)						
Longitudinal	1	176,000	228,000	11.4	49.4	444
"	2	185,000	230,000	12.1	47.0	
"	3	182,000	231,000	11.4	49.0	
"	4	177,000	230,000	12.1	49.0	
Longitudinal Average		180,000	229,750	11.8	48.6	
Transverse	1	---	230,000	9.3	37.6	
"	2	184,000	231,000	9.3	38.5	
"	3	210,000	231,000	10.0	38.0	
"	4	177,000	227,500	9.3	39.8	
Transverse Average		190,300	229,900	9.5	38.5	
SAMPLE 2 (Medium Tank T-34)						
Top Sloping Front Plate (1-7/8" Rolled Homogeneous						
Longitudinal	1	176,000	220,500	10.7	39.4	444 - 461
"	2	179,000	224,000	12.1	47.0	
"	3	181,000	221,500	10.7	44.5	
"	4	177,000	221,000	11.4	47.0	
Longitudinal Average		178,250	221,750	11.2	44.5	
Transverse	1	184,000	222,000	8.6	32.6	
"	2	177,000	221,000	7.9	33.1	
"	3	178,000	217,500	9.3	31.2	
"	4	181,000	220,000	7.1	34.5	
Transverse Average		180,000	220,100	5.2	32.9	

TABLE III (Cont.)

Direction of Tensile Specimen	Yield Strength 0.1% Offset psi.	Tensile Strength psi.	Elongation %	Red. of Area %	Brinell Hardness
SAMPLE 2 (Medium Tank T-34)					
Hull Roof Plate (3/4" Rolled Homogeneous)					
Transverse 1	167,000	215,000	7.1	30.8	429
" 2	166,000	210,000	8.6	32.6	
Transverse Average	166,500	212,500	7.9	31.7	
SAMPLE 3 (Medium Tank T-34)					
Top Plate (5/8" Rolled Homogeneous)					
Longitudinal 1	219,000	270,000	10.0	38.9	495
" 2	215,000	262,000	9.3	39.8	
Longitudinal Average	217,000	266,000	9.7	39.4	
Transverse 1	211,000	275,000	7.1	27.0	
" 2	204,000	267,000	7.1	26.0	
" 3	205,000	267,000	7.1	26.5	
Transverse Average	207,700	269,700	7.1	26.5	
Turret Sidewall (2-3/8" Cast Homogeneous)					
1	160,000	218,000	4.3	11.9	444 - 495
2	161,000	223,000	5.0	11.9	
3	159,000	216,000	6.4	16.6	
Average	160,000	219,000	5.2	13.5	
SAMPLE 4 (Heavy Tank KV-1)					
Top Plate (1-1/4" Rolled Homogeneous)					
Longitudinal 1	133,000	153,000	15.7	59.6	321
" 2	136,000	155,000	14.3	58.1	
" 3	136,000	155,000	15.0	58.1	
" 4	130,000	152,000	15.0	58.5	
Longitudinal Average	133,750	153,750	15.0	58.6	
Transverse 1	132,000	154,000	14.3	49.8	
" 2	136,000	153,000	14.3	47.4	
" 3	129,000	149,000	12.9	48.6	
" 4	138,000	154,500	14.3	49.4	
Transverse Average	133,750	152,600	14.0	48.8	
Turret Sidewall (3-5/8" Cast Homogeneous)					
1	120,000	140,000	8.6	17.6	285 - 293
2	120,000	141,500	12.1	26.0	
3	120,000	140,500	12.1	25.5	
4	119,000	141,500	10.7	23.6	
Average	119,750	140,900	10.9	23.2	

TABLE IV

Chemical Analyses of Weld Metal Deposits

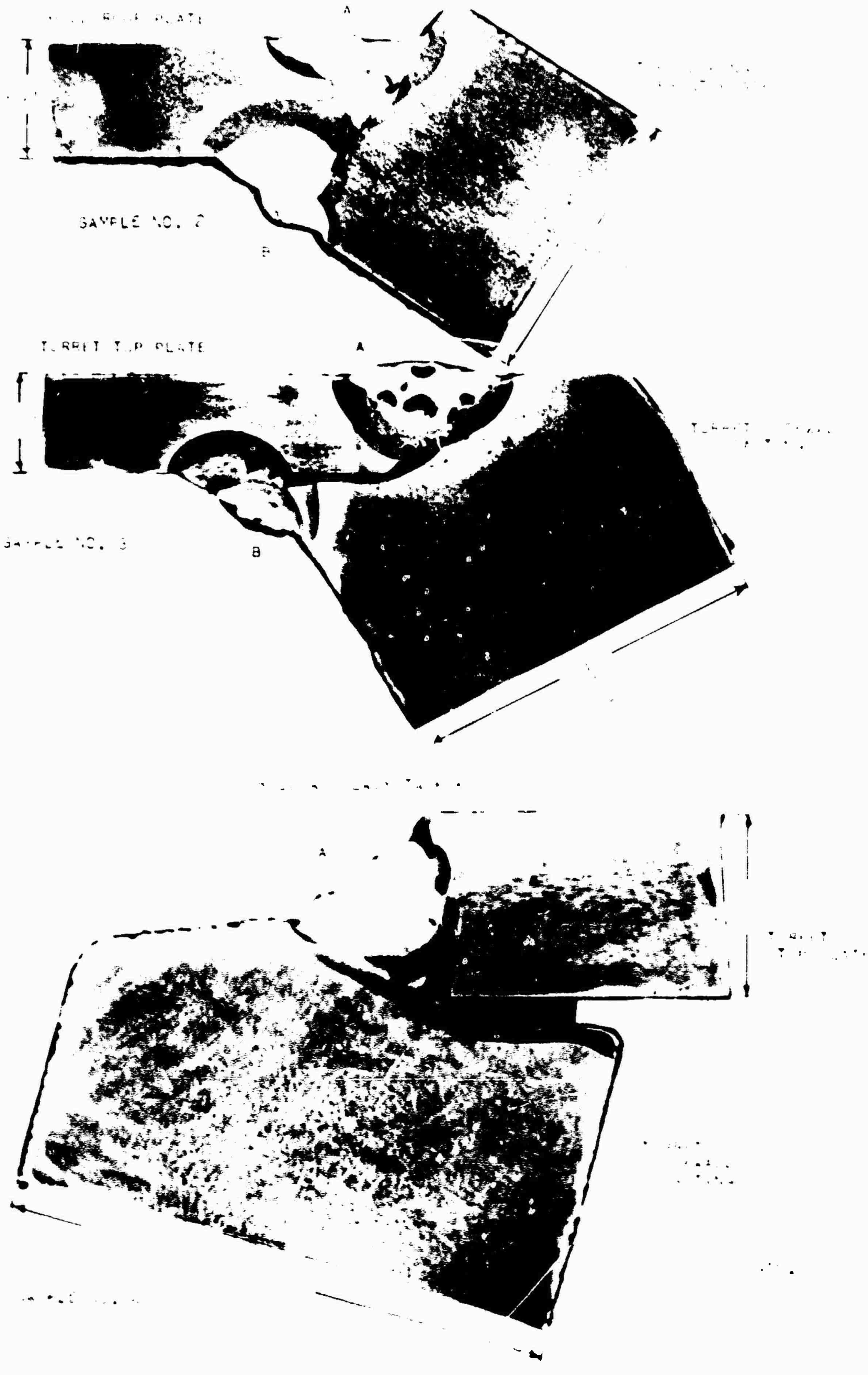
	Weld Deposit	C	Mn	Si	Ni	Cr	Mo	V
					MEDIUM TANK T-34			
Sample No. 1 (Figure No. 1)	B	.07	.97	.75	.24	.20	.05	Nil
	C	.10	1.03	.91	.49	.34	.09	"
	D	.08	.93	.63	.16	.17	.03	"
Sample No. 2 (Figure No. 2)	A							
	Ferritic Crown	.10	.98	.63	2.97	4.82	.06	Nil
	Austenitic Body	.11	.82	.48	6.06	10.02	.08	"
	B	.10	.81	.50	.37	.16	.10	"
Sample No. 3 (Figure No. 2)	A	.08	.89	.72	.18	.19	.27	Nil
	B	.12	.74	.63	.18	.13	.26	"
					HEAVY TANK KV-1			
Sample No. 4 (Figure No. 2)	A							
	Root Passes	.15	.51	.11	.55	.51	.09	Nil
	Crown Passes	.19	.57	.41	12.12	19.97	.10	"

TABLE V

Summary of Hardness Survey Results on Welded Joints

	Weld Metal Hardness Vickers	Weld Metal Hardness Brinell*		Weld Heat-Affected Zone: Maximum Hardness Vickers	Weld Heat-Affected Zone: Maximum Hardness Brinell*	Weld Heat-Affected Zone: Minimum Hardness of Tempered Zone Vickers	Weld Heat-Affected Zone: Minimum Hardness of Tempered Zone Brinell*	Base Metal Brinell
Medium Tank T-34, Sample No. 1 (Figure 1)								
Deposit A - crown	233-249	232-244	Front Plates	493	453	317	300	430-444
body and root	264-345	240-324						
Deposit B - crown	172-188	172-189	Bow Casting	498	459	262	255	200-248
body and root	227-258	229-252						
Deposit C - body and root	245-264	240-257						
Deposit D - side bead	256-283	250-272						
other weld metal	185-221	186-222						
Medium Tank T-34, Sample No. 2 (Figure 2)								
Deposit A - crown	401-429	370-396	Hull Roof Plate	325	307	264	257	429
body (austenitic)	198-209	199-211						
root	191-213	192-214						
Deposit B - top bead	227-238	229-235	Top Sloping Front Plate	514	471	312	296	444-461
body	182-197	185-198						
Medium Tank T-34, Sample No. 3 (Figure 2)								
Deposit A - crown	221-245	232-240	Turret Top Plate	478	441	294	281	495
root	230-317	230-294						
Deposit B - crown	243-309	239-293	Turret Sidewall Casting	508	466	314	298	444-495
root	256-345	250-324						
Heavy Tank KV-1, Sample No. 4 (Figure 2)			Turret Top Plate	483	445	276	268	321
Deposit A - crown (austenitic)	196-228	197-234						
root	192-238	193-235	Turret Sidewall Casting	446	413	297	283	285-293

* Converted from Vickers-Brinell to Standard Brinell (Steel Ball, 3000 KV load)


A
SAMPLE NO. 2
B
TURRET TOP PLATE
A
SAMPLE NO. 3
B
A

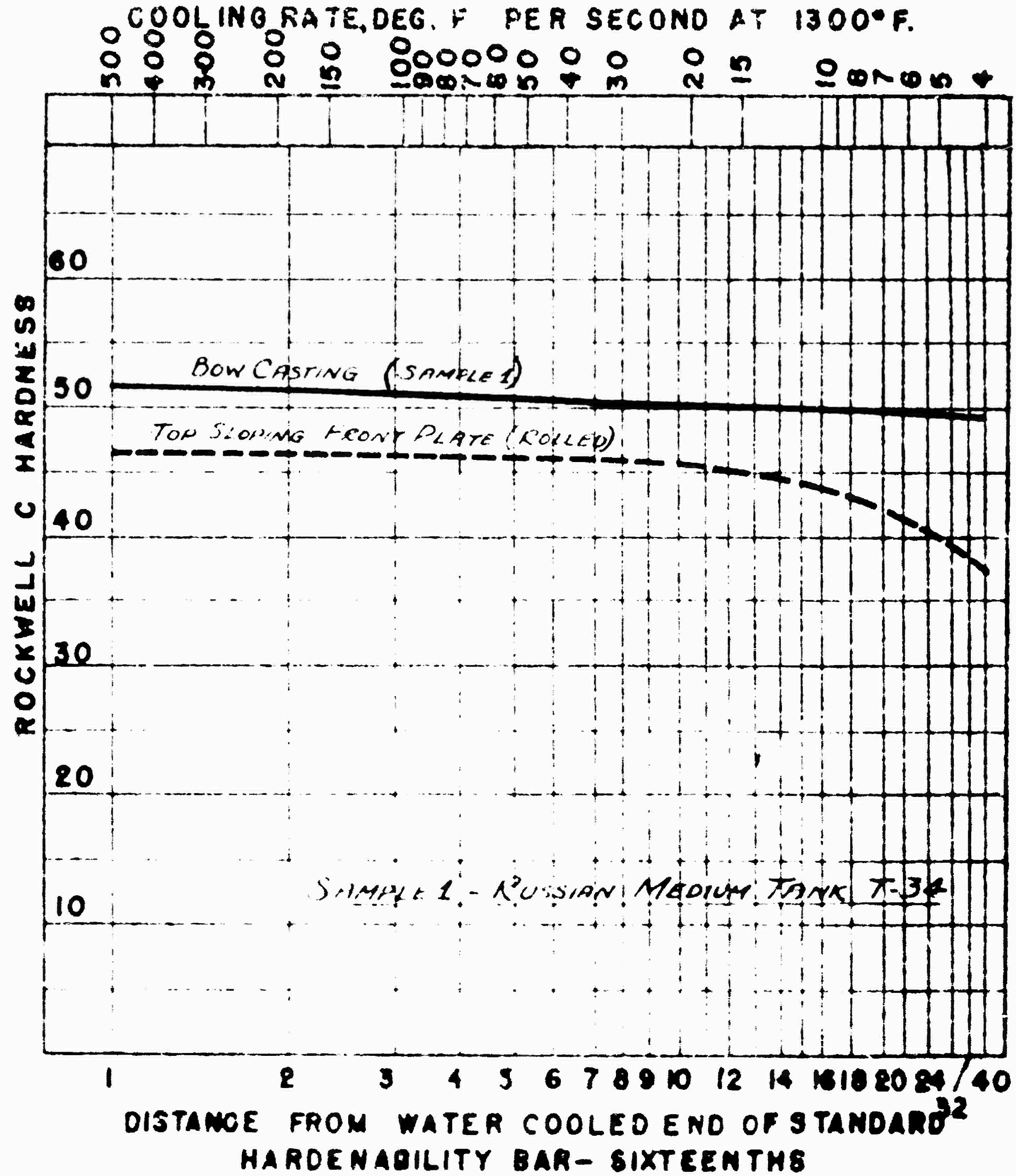


PLATE NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	MO	CU	AL	QUENCH TEMP	QUENCH TIME	G.S.
BOW CASTING		.29	1.55	2.29	.021	.029	1.52	1.05	.25	.12	.015	1675	3	
FRONT PLATE		.23	1.20	1.10	.026	.021	1.26	.5	.215	.09	.025	1675	3	

JOMINY HARDENABILITY

FIGURE 3

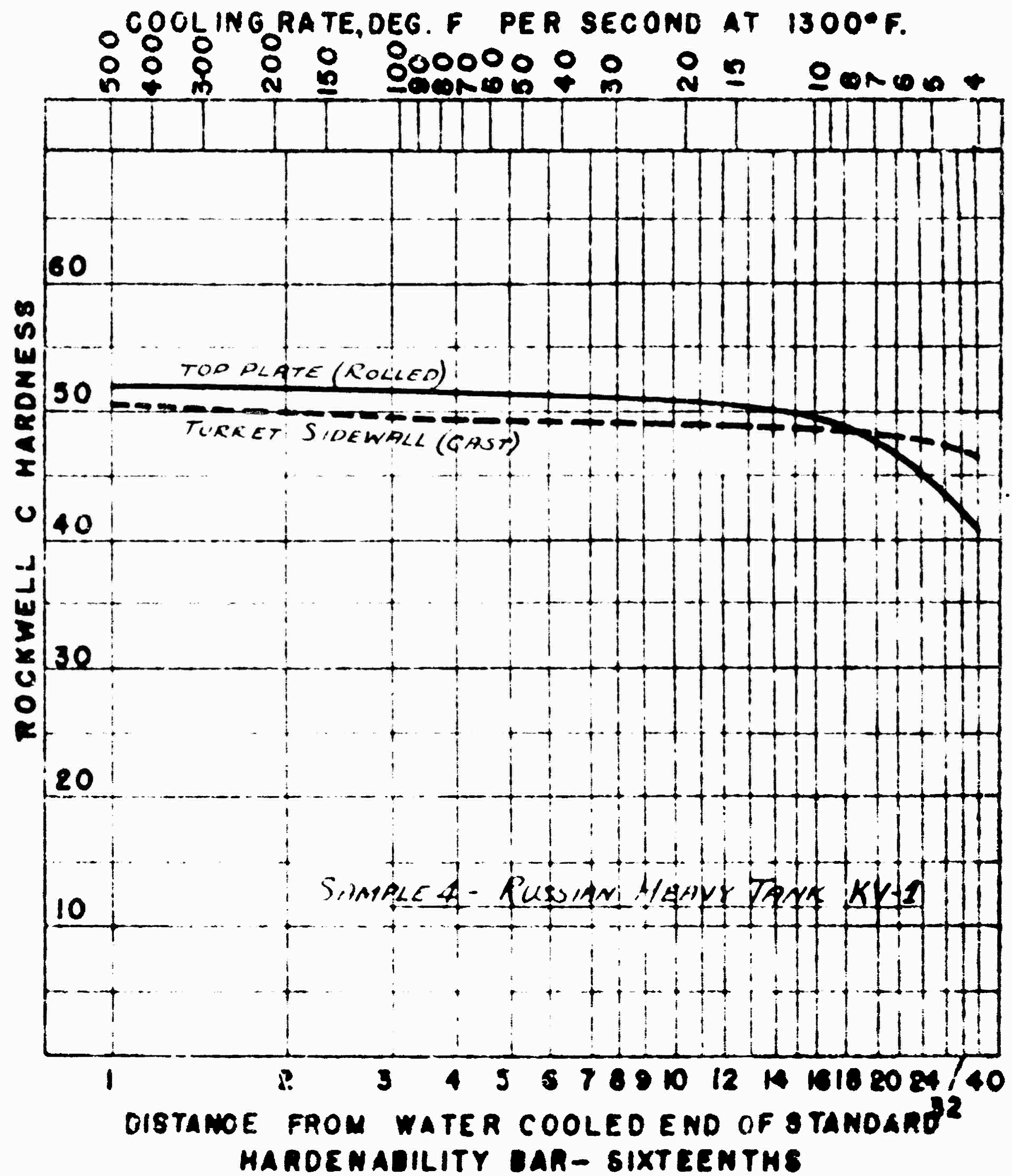
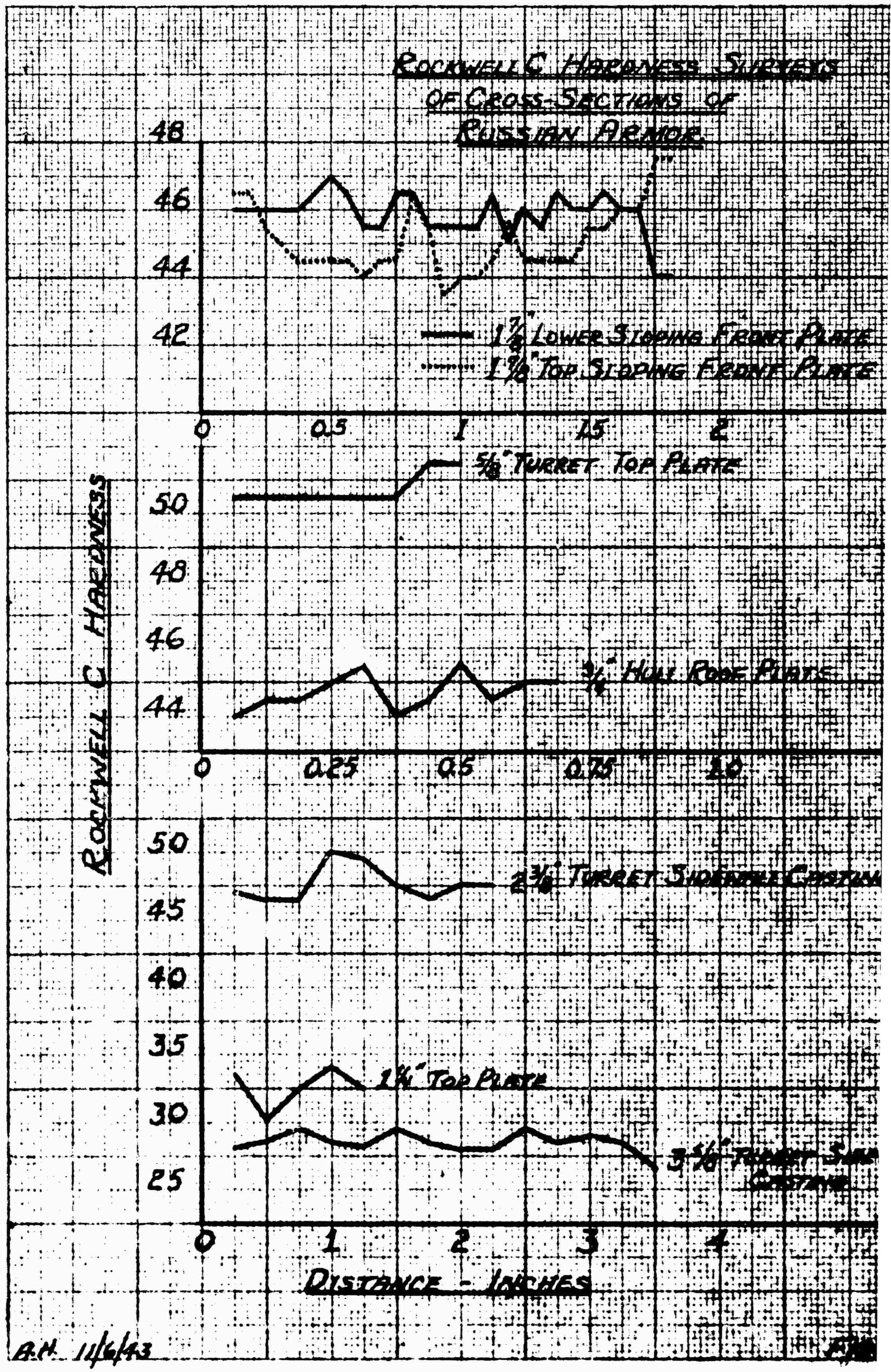


PLATE NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	MO	CU	AL	QUENCH TEMP	QUENCH TIME	G.S.
Top Pl	ate	.32	.41	.32	.016	.018	.16	2.34	.25	.11	.015	1675	3	
Turret	Sidewall	.30	.44	.34	.041	.016	2.91	1.47	.27	.10	.02	1675	3	
		Jominy	Hardenability											

FIGURE 4



ROCKWELL C HARDNESS SURVEYS
OF CROSS-SECTIONS OF
RUSSIAN ARMOR
ROCKWELL C HARDNESS
48
46
44
42
1 7/8" LOWER SLOPING FRONT PLATE
1 1/2" TOP SLOPING FRONT PLATE
0
0.5
1
1.5
2
5/8" TURRET TOP PLATE
50
48
46
44
3/4" HULL ROOF PLATE
0
0.25
0.5
0.75
1.0
50
45
40
35
30
25
2 3/8" TURRET SIDE
1 1/4" TOP PLATE
3 5/8" TURRET SIDE
CASTING
0
1
2
3
4
DISTANCE - INCHES

B.H. 11/6/43

Russian T-34 Medium Tank (Sample 1)

1-7/8" Lower Sloping Front Plate (Rolled Homogeneous Armor)

Longitudinal Transverse

Hot Acid Macroetch -A- X1

Moderately clean steel. Residual ingotism evident.

X100 -B- Unetched

Moderately clean steel. Occasional inclusions, usually well scattered.

X100 -C- Nital-Picral

Homogeneous acicular structure. A.S.T.M. grain size - #7-8.

X1000 -D- Nital-Picral

Martensite free of high temperature transformation products. Possibly tempered at some temperature not over 600°F.

FIGURE [illegible]

Russian T-34 Medium Tank (Sample 1)

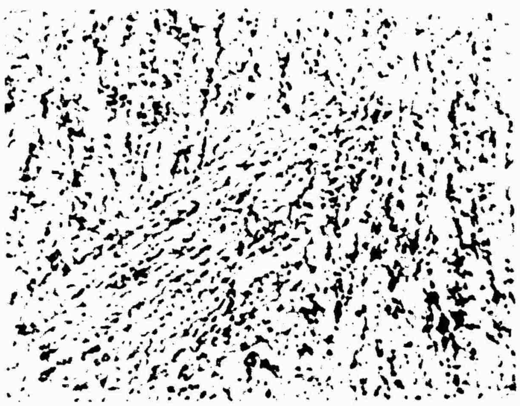
Bow Casting

Hot acid macroetch — -A- — X1½

Very coarse grained macrostructure. Porous casting.

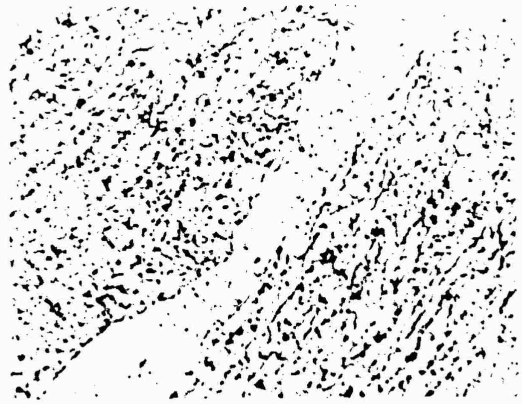
X100 — -B- — Nital-Picral

Acicular Widmanstatten structure. Ferrite envelopes at austenite grain boundaries.



X1000 — -C- — Nital-Picral

Typical orientation of carbides in ferrite. Probable heat treatment consisted of tempering after casting.



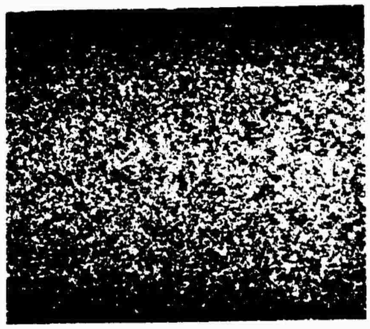
X1000 — -D- — Nital-Picral

Ferrite envelope such as shown in -B-. Spheroidized carbides present in ferrite at grain boundaries.

FIGURE 7

Russian T-34 Medium Tank (Sample 2)

1-7/8" Top Sloping Front Plate (Rolled Homogeneous Armor)



Longitudinal -A- Transverse

Hot acid macroetch X1

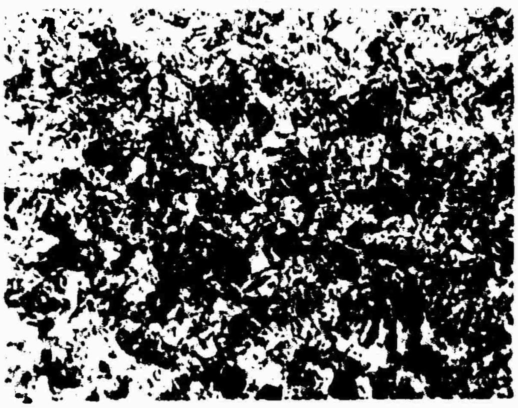
Poor quality steel apparently straight-away rolled.

X100 -B- Unetched

Poor quality steel. Typical elongated stringer composed of small friable alumina-type inclusions.

X100 -C- Unetched

Stringers of silicate type inclusions also present in large numbers.



X100 -D- Nital-Picral

Homogeneous acicular structure. A.S.T.M. grain size - #6.

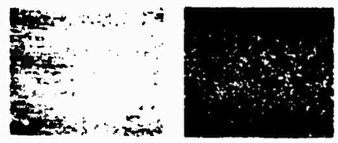
X1000 -E- Nital-Picral

Small amounts of ferrite and pearlite rejected at martensite grain boundaries. Possibly tempered at low temperature.

FIGURE 8

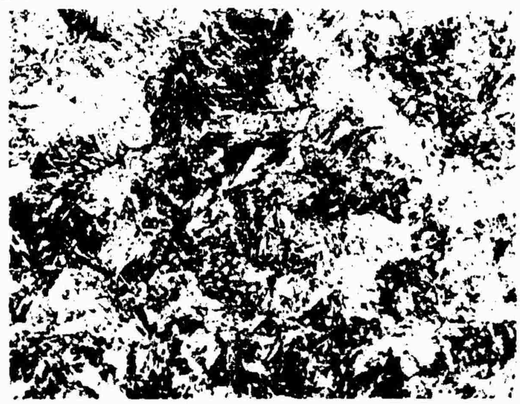
Russian T-34 Medium Tank (Sample 2)

3/4" Hull Roof Plate (Rolled Homogeneous Armor)



Longitudinal   Transverse
Hot acid macroetch -A- X1
Poor quality steel apparently straight-away rolled.

X100 -B- Unetched
Poor quality steel. Very high concentration of elongated inclusions.



X100 -C- Nital-Picral
Acicular structure with feathery patches of ferrite at grain boundaries. A.S.T.M. grain size #4-5.

X1000 -D- Nital-Picral
Typical microstructure. Martensite grains with ferrite and pearlite at grain boundaries. Incompletely quench hardened. Possibly tempered at low temperature.

X1000 -E- Nital-Picral
Typical of less completely quench hardened areas. Grains of pearlite and martensite with rejected ferrite at grain boundaries.

FIGURE 9

Russian T-34 Medium Tank (Sample 3.)

5/8" Turret Top Plate (Rolled Homogeneous Armor)

Longitudinal Transverse

Hot Acid Macroetch -A- X1
Sound Steel apparently straight-away rolled.

X100 -B- Nital Picral
Homogeneous acicular microstructure, A.S.T.M. grain size - 4.

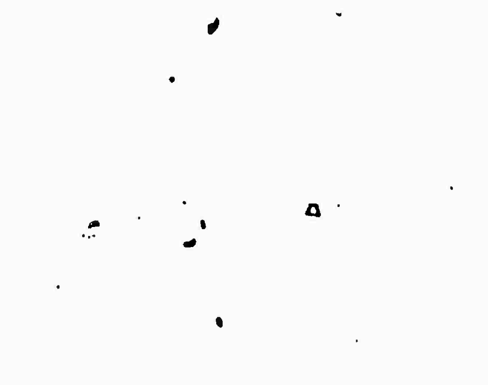
X1000 -C- Nital Picral
Completely martensitic microstructure. Possibly tempered at low temperature.

FIGURE 10

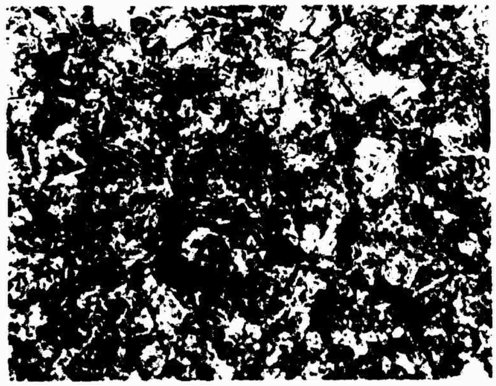
Russian T-34 Medium Tank (Sample [illegible].)

2-3/8" Turret Sidewall (Cast Homogeneous Armor)

Hot Acid Macroetch -A- X1
Centerline shrinkage in an otherwise dense structure.



X100 -B- Unetched
Moderately clean steel. Globular inclusions not segregated in any manner.



X100 -C- Nital Picral
Homogeneous acicular structure. A.S.T.M. grain size - #5.

X1000 -D- Nital Picral
Structure found in many dendrite axes. Ferrite and pearlite rejected at martensite grain boundaries.

X1000 -E- Nital Picral
Structure typical of dendritic fillings. Martensite free from high temperature transformation products. Possibly tempered at low temperature.

FIGURE 11

Russian KV-1 Heavy Tank (Sample [illegible])

<u>1½" Top Plate (Rolled Homogeneous Armor)</u>

Longitudinal　　　Transverse

Hot Acid Macroetch　　　-A-　　　X1

Moderately dirty steel. Steel has been cross rolled.

X100　　　-B-　　　Unetched

Typical elongated inclusions. Moderately dirty steel.

X100　　　-C-　　　Nital Picral

Moderately banded structure. Lighter etching regions are richer in ferrite. A.S.T.M. grain size - #8.

X1000　　　-D-　　　Nital Picral

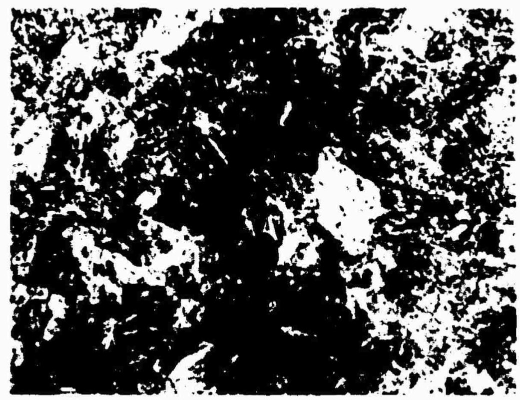
Tempered martensite with ferrite and carbides resulting from partial transformation at elevated temperatures. Incompletely quench hardened.

Russian KV-1 Heavy Tank (Sample 4)

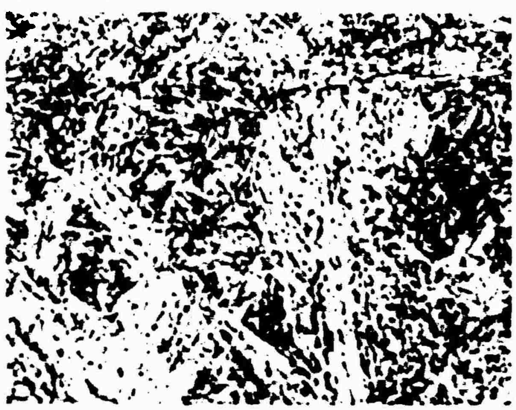
3-5/8" Turret Sidewall (Cast Homogeneous Armor)

Hot acid macroetch -A- X1
Large number of hot tears extending for considerable depth into metal.

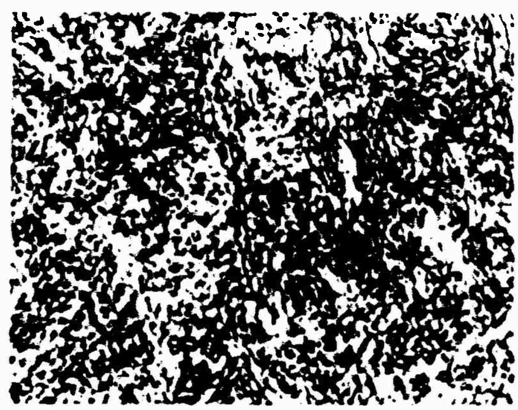
X100 -B- Unetched
Clean steel. Well scattered globular inclusions.



X100 -C- Nital-Picral
Relatively homogeneous structure. A.S.T.M. grain size - #4-5.

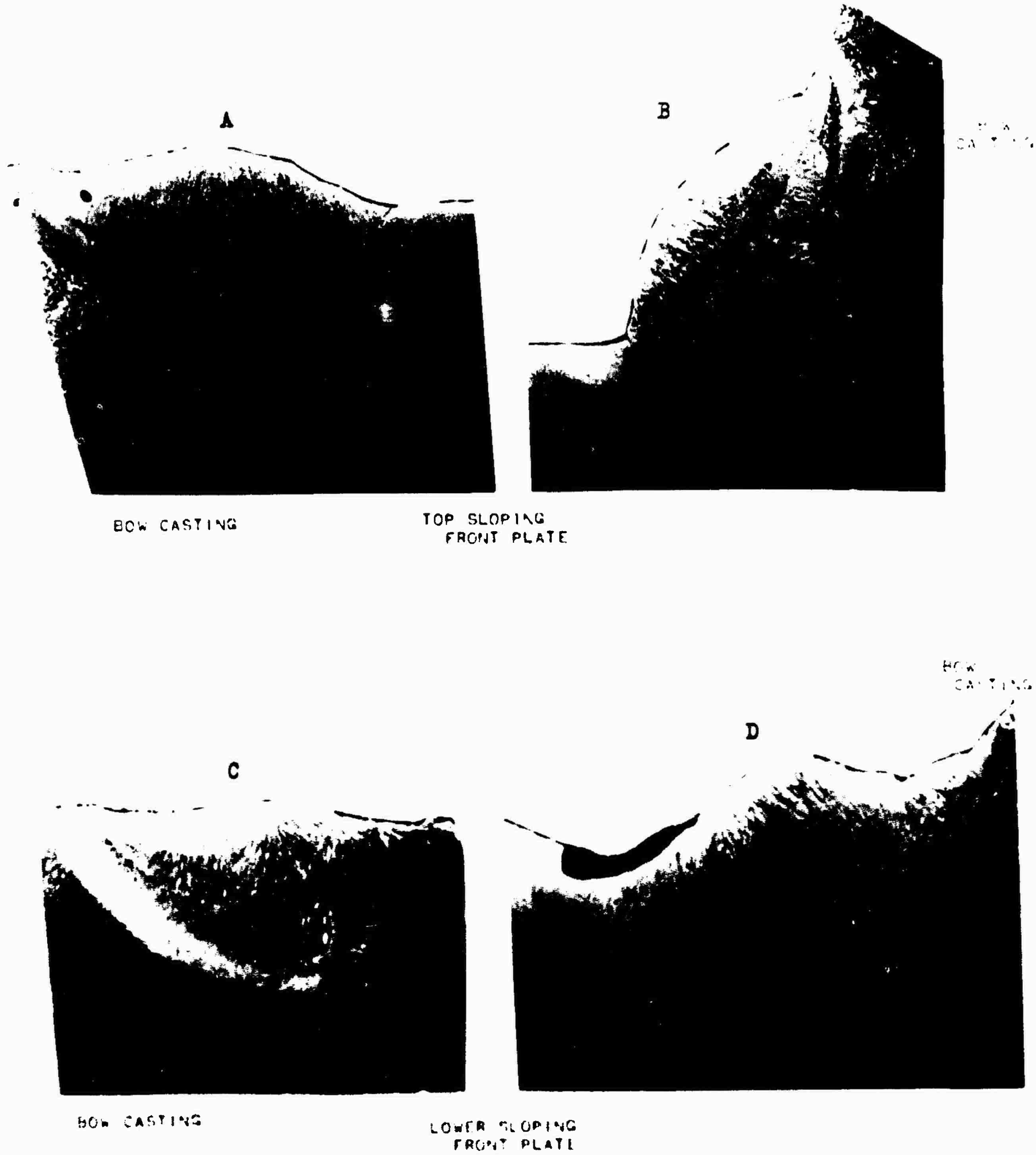


X1000 -D- Nital-Picral
Tempered martensite, with small amounts of ferrite and carbides resulting from high temperature transformation found in dendritic axes.



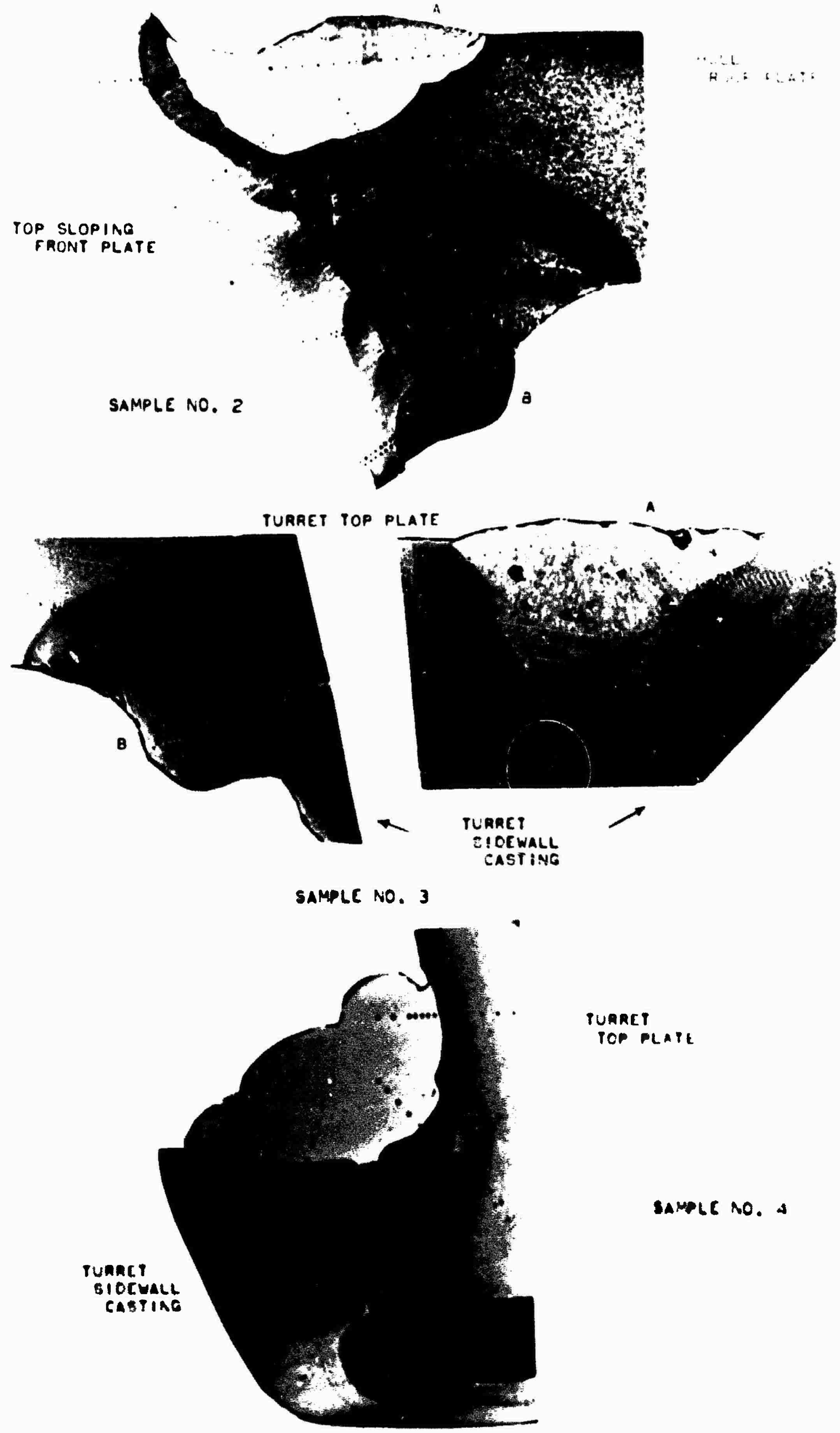
X1000 -E- Nital-Picral
Tempered martensite typical of major portion of microstructure.

FIGURE 13



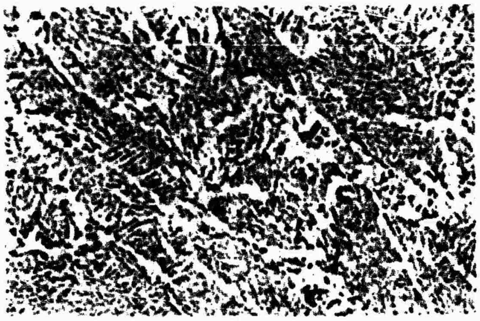
ETCH: 5% NITAL FOLLOWED BY 4% PICRAL

FIGURE 14. MACROETCHED SECTIONS THROUGH WELD DEPOSITS OF SAMPLE NO. 1, RUSSIAN MEDIUM TANK T-34. SEE FIGURE 1 FOR LOCATION OF WELD DEPOSITS IN JOINTS.



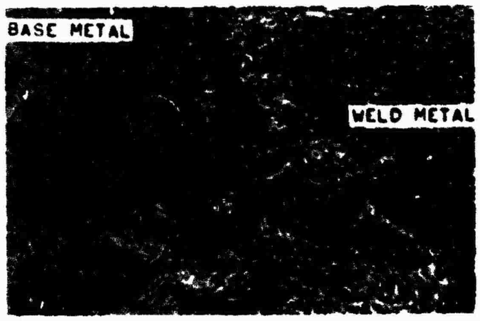
X2 ETCH: 5% NITAL FOLLOWED BY 4% PICRAL

FIGURE 15. MACROETCHED SECTIONS THROUGH WELD DEPOSITS OF SAMPLES NO. 2 AND 3, RUSSIAN MEDIUM TANK T-34, AND SAMPLE NO. 4, RUSSIAN HEAVY TANK KV-1. SEE FIGURE [illegible] FOR LOCATION OF WELD DEPOSITS IN JOINTS.



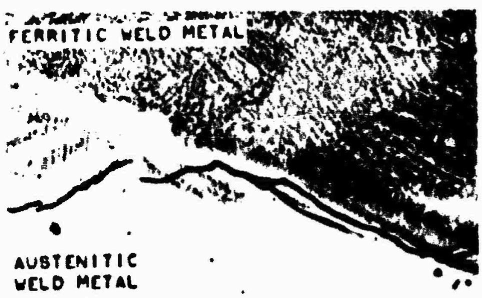
X100 PICRAL
WELD METAL. SAMPLE NO.1. DEPOSIT D.

X100 PICRAL
JUNCTION OF WELD AND LOWER FRONT PLATE
SAMPLE NO.1. DEPOSIT C.

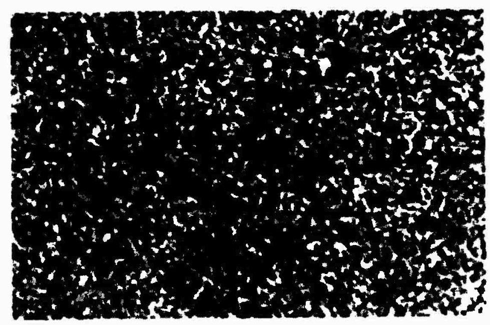


X100 PICRAL
JUNCTION OF WELD AND LOWER FRONT PLATE.
SAMPLE NO. 1. DEPOSIT D.

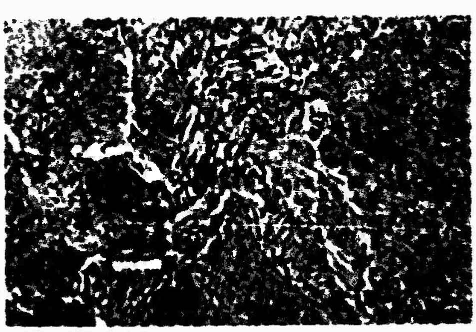
X100 PICRAL
JUNCTION OF FRONT PLATE, AUSTENITIC, AND
FERRITIC DEPOSITS. SAMPLE NO. 2. DEPOSIT A.



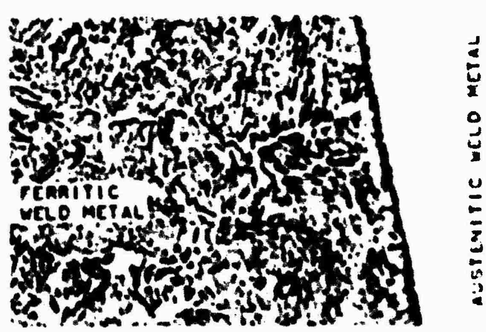
X100 PICRAL
CRACK AT FUSION LINE OF WELD BEADS.
SAMPLE NO. 2. DEPOSIT A.



X100 PICRAL
WELD METAL. ROOT BEAD. SAMPLE NO. 3.
DEPOSIT A.



X100 PICRAL
WELD METAL. CROWN BEAD. SAMPLE NO.3.
DEPOSIT A.



X250 PICRAL
JUNCTION OF AUSTENITIC AND FERRITIC WELD
DEPOSITS. SAMPLE NO. 4. DEPOSIT A.

FIGURE 16. PHOTOMICROGRAPHS OF WELD JOINTS IN RUSSIAN MEDIUM TANK
T-34 AND HEAVY TANK KV-1.

APPENDIX A

Basic Correspondence

COPY - 26 November 1943 - ahk **SECRET**

WAR DEPARTMENT
Office of the Chief of Ordnance
Washington, D. C.

27 August 1943

O.O. 400.112/4376(s)
Attn: Steel and Welding

Subject: Sample Sections of Russian KV1 and T34 Tanks

To: Commanding Officer
Watertown Arsenal
Watertown, Mass.

Attn: Colonel H. H. Zornig

1. Aberdeen Proving Ground has been instructed to send to Watertown Laboratory, selected samples of armor and welding from Russian tanks in accordance with the attached sketches A, B, and C, dated 27 August 1943.

2. A complete metallurgical examination is to be made covering rolled homogeneous, cast armor and weldments.

3. It is requested a complete cross section of each specimen 1/4" to 1/2" wide, showing rolled homogeneous, cast armor and weld, be cut and machined on both sides, polished, etched in a manner to bring out bead sequence, and coated for protection. These are to be sent to the office of Colonel G. Elkins Knable, Special Steels and Welding Section, Technical Division, Washington, D. C., as soon as possible.

4. A similar section is to be cut, but unpolished, and set aside for future analysis by an outside agency if it is found desirable.

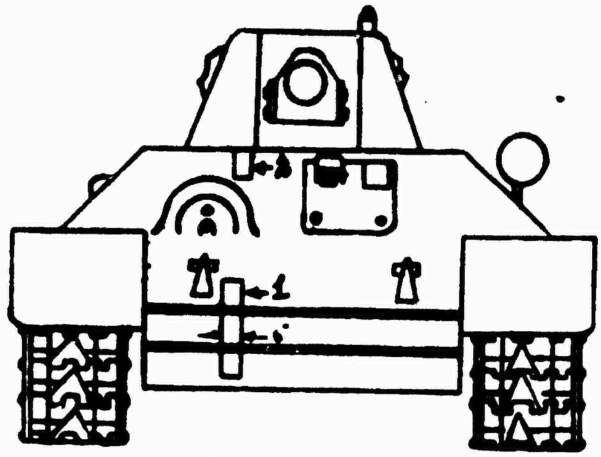
By order of the Chief of Ordnance:

(s/t) G. Elkins Knable
Colonel, Ord. Dept.
Assistant

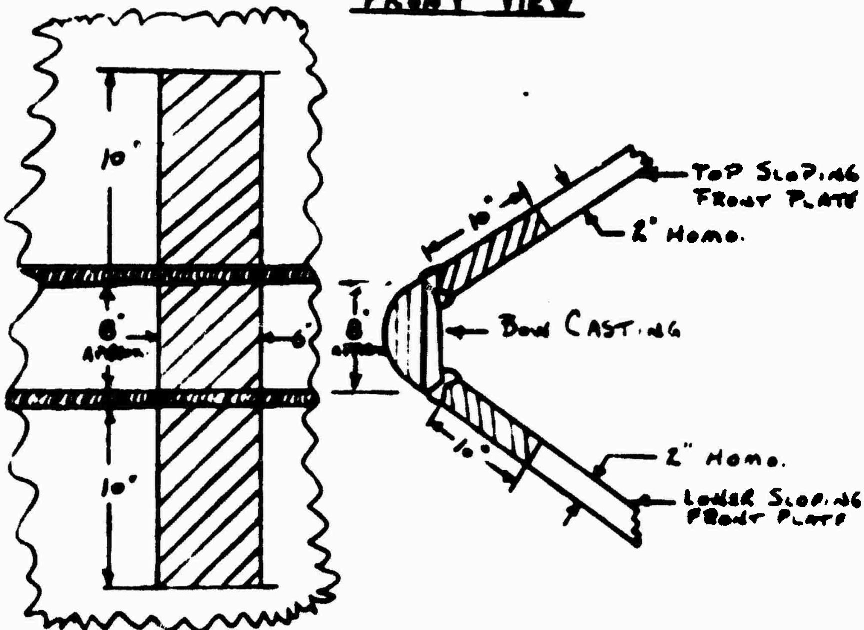
3 Incls.
As indicated above.
CC - Col. S.B. Ritchie
Capt. E.S. Davis
Lt. H.F. Brown
Lt. L.J. Cogan
Major J.V. Coombe

Wtn. 451.25/157(s)

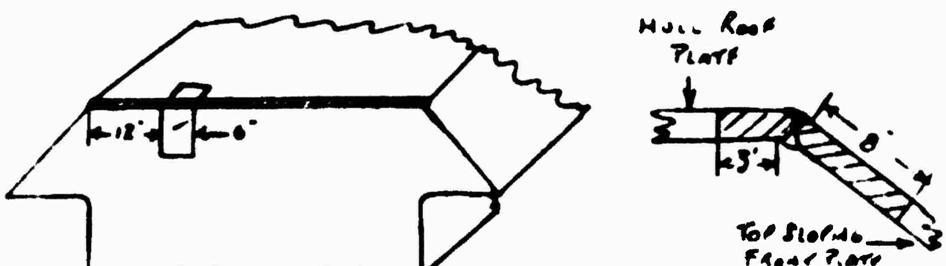
RUSSIAN MEDIUM TANK T-34



FRONT VIEW



DETAIL OF SAMPLE 1



DETAIL OF SAMPLE 2

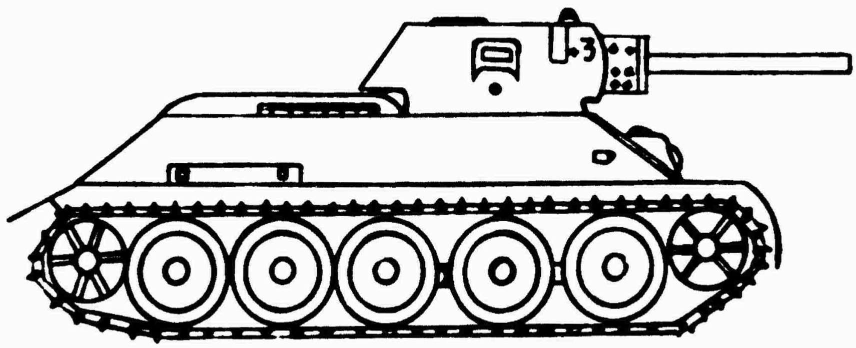
POSITION OF SELECTED SAMPLES FOR METALLURGICAL EXAMINATION

SKETCH A

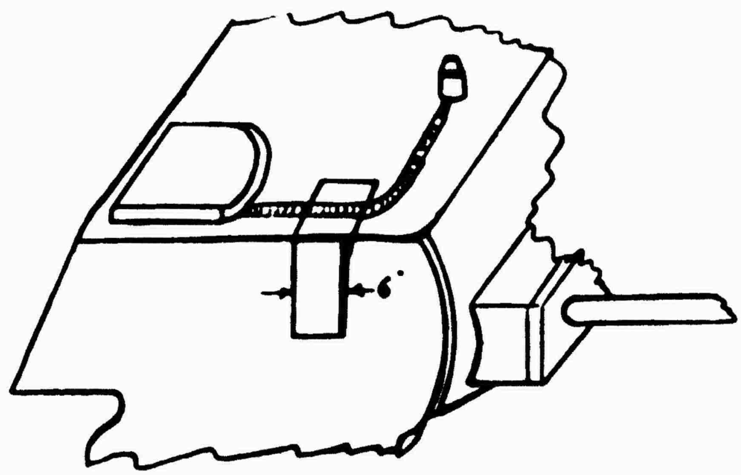
NOTE: ALL DIMENSIONS ARE ± ½"

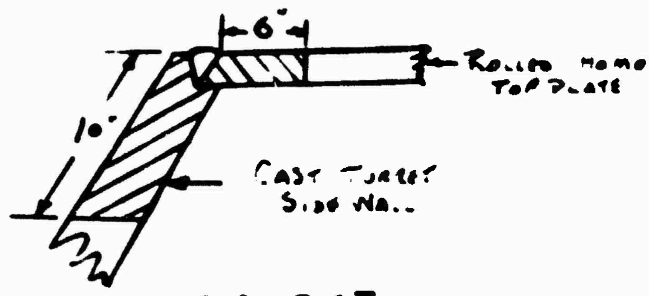
27 AUGUST 1943

Russian Medium Tank T-34



Side View
Right Elevation





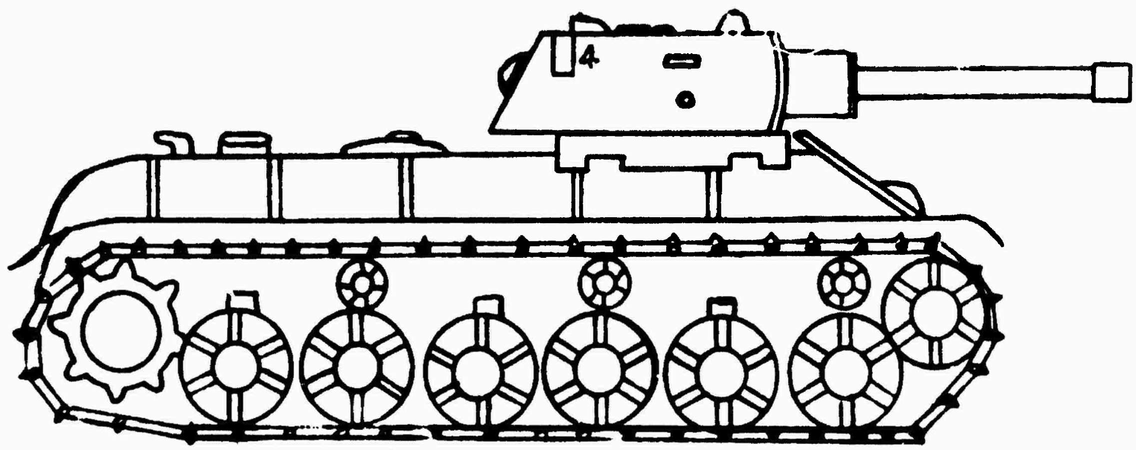
Detail of Sample 7

Position of Selected Samples for Metallurgical Examination

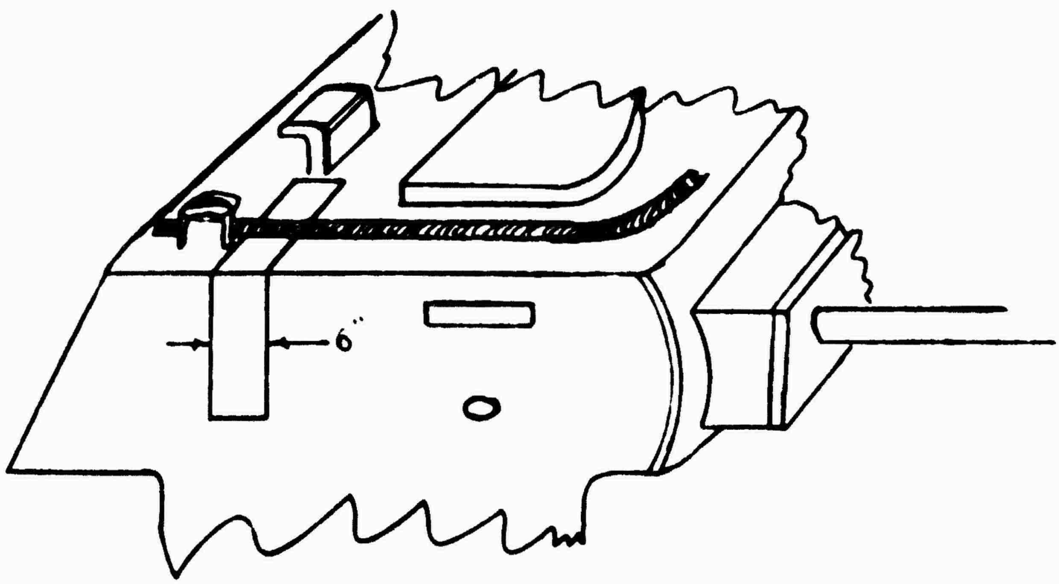
Sketch B

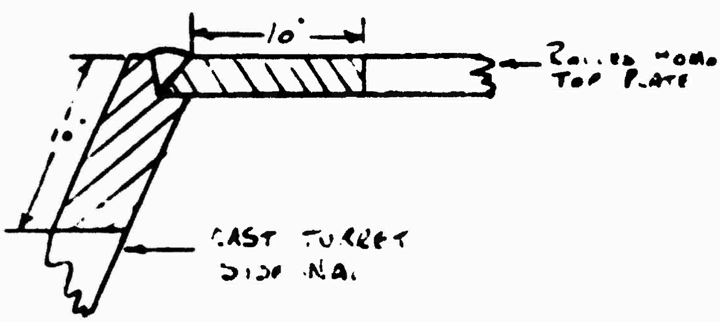
Note: All dimensions are ±¼" 27 J[illegible] 1943

RUSSIAN HEAVY TANK KV1



SIDE VIEW
RIGHT ELEVATION





DETAIL OF SAMPLE 4

POSITION OF SELECTED SAMPLE FOR METALLURGICAL EXAMINATION

SKETCH C

NOTE ALL DIMENSIONS ARE